

Costing Studies for ARPA-E Fusion Projects

**Fusion Review Meeting
April 26-27, 2022**

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Simon Woodruff, Woodruff Scientific, Inc.

Goals and Approach

- ▶ Help project teams estimate projected overnight capital costs of fusion power plants
 - particularly ARPA-E Open 2018 and BETHE projects
- ▶ Help guide R&D priorities by illuminating costliest aspects of concepts
- ▶ Improve existing costing model by benchmarking against other fusion costing codes
- ▶ Improve model by developing cost model for reduced scale fusion tritium-processing system

Collaboration: PPPL and Woodruff Scientific, Decysive systems, others

Team members and roles

Simon Woodruff, Woodruff Scientific
Co-Pi

Lead on Cost Model;
Costing of ARPA-E
Fusion Concepts



Michael Zarnstorff, PPPL
PI

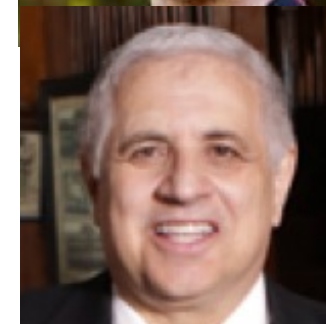
Lead on Benchmarking;
Tritium System Model
and Costing



Mark Anderton, Oxford Sigma
Code automation



Charles Gentile, PPPL
Tritium Systems



Ken Hammond, PPPL
PROCESS modeling



Charles Swanson, PPPL
PROCESS modeling

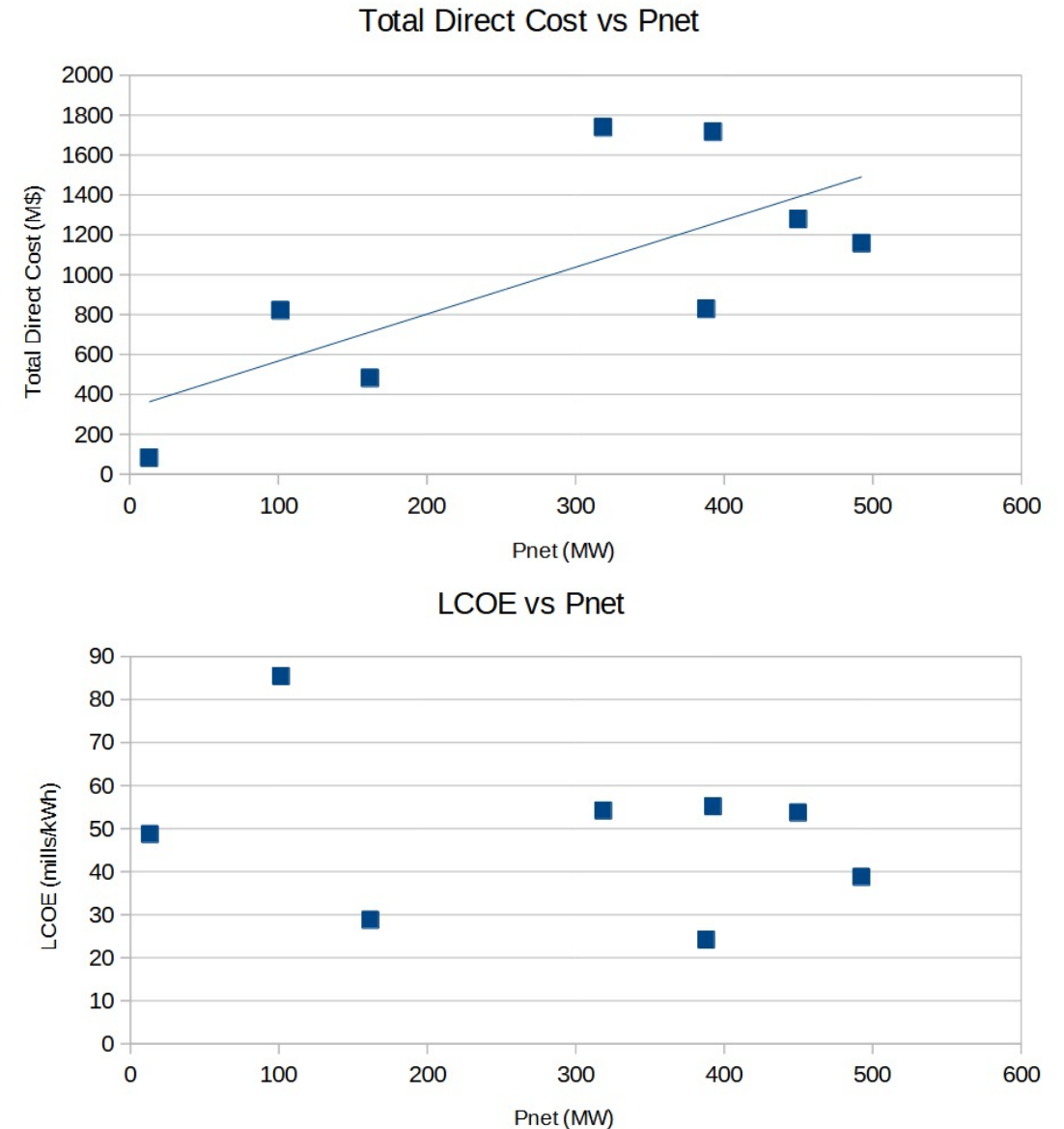


Tasks and Milestones

1. Analyze Nth-of-a kind costs and cost drivers for ARPA-E fusion projects
2. Benchmarking Costing Model with PROCESS
Menard 2016 pilot plant modeled & costed with PROCESS, components costed with WS code
3. Develop tritium systems cost scaling
Tritium system modeled & optimized vs power. Model costs to achieve acceptable solutions.

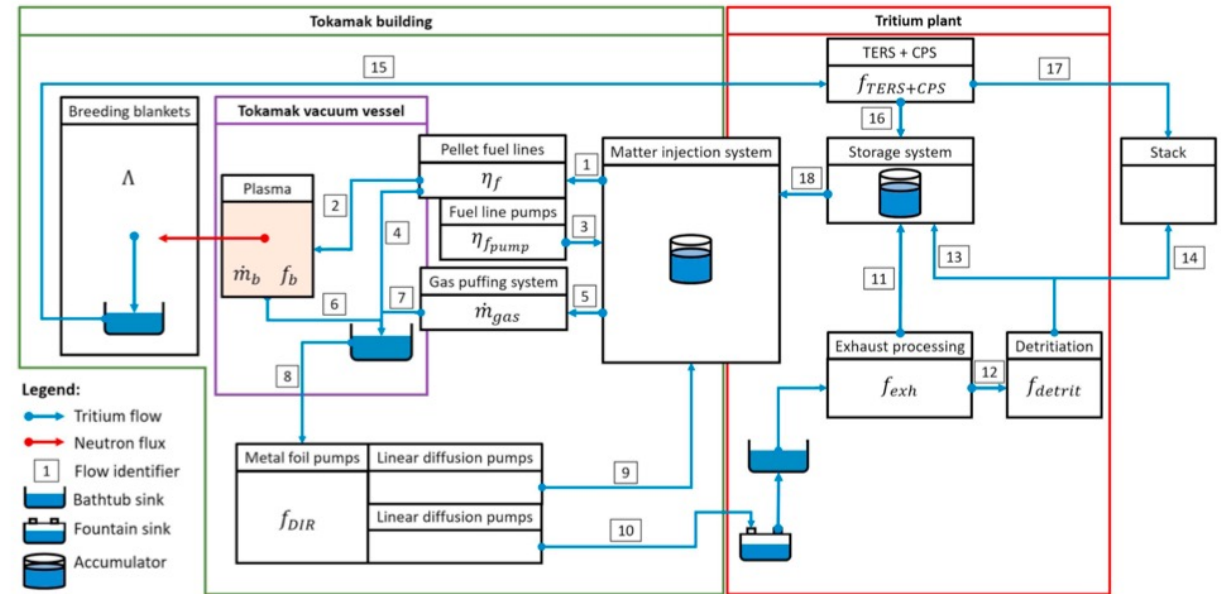
Fusion Concept Construction Cost Modeling

- ▶ Thirteen concepts analyzed
 - Nth of a kind construction & operating costs; LCOE
 - Cost Driver analysis
 - 2nd & 3rd iteration analysis, responding to requested scenarios, including improved models
- ▶ In most cases, analysis involves proprietary information, only shared with Woodruff Scientific, Inc.



Tritium System Model (for DT based Concepts)

- ▶ Key metrics:
 - Tritium inventory: accident severity
 - Activated waste exhaust to environment (Goal: < 0.1 g/year/GWe, for PWR)
- ▶ Important parameters
 - Fusion burnup fraction and fueling efficiency (inventory)
 - Rapid recirculation of fuel (inventory)
 - High separation efficiency (exhaust)
 - T-control during maintenance
- ▶ Inventory and exhaust \propto fusion power



From M.Coleman et al, FED 2019

- ▶ Technical methods exist, in principle
 - Most available commercially
 - GAMOW projects working on improvements & new methods

Cost Model Benchmarking

- ▶ Benchmarked Woodruff Cost Code against PROCESS (CCFE)
- ▶ Use ST Pilot Plant (J.Menard NF 2016)
- ▶ Improvements made to both codes in response to comparison
- ▶ For most costs, PROCESS cost estimate > Woodruff model. Some vice versa. Factor of < 1.9 for total plant direct cost.
- ▶ Different basis of estimate & method
 - Woodruff model now based mainly on recent cost data
 - PROCESS: escalation of 1980s & 1990s models (Generomak, Starfire)



Cost of copper over 60 year time-frame.

- ▶ Escalation of old estimates not reliable
 - Material costs not tied to inflation
 - Does not include improved technologies, modeling, manufacturing efficiency
- ▶ Also: difference in detailed design choices

T2M impact and aspirational follow-on plans

- ▶ Provide costing feedback on evolving designs and technology maturation
 - Indicate important directions for improved economics
- ▶ Evaluate new concepts and approaches
 - IFE
- ▶ Compare costing model with SMR fission costing models
- ▶ Develop analysis requested by groups
 - First of a kind (technology selection and vendor quotes)
 - Scenarios (for different markets, for different powers, for different technologies)
 - Sensitivity analysis - some versions are now coupled to the physics inputs, so can look at impact of physics on the LCOE
 - Advanced manufacturing methods, impact on cost drivers.
 - Neutronics analysis to determine materials thicknesses
 - Publish papers on results